MODELLING THE RELATIONSSHIP BETWEEN URBAN ENVIRONMENT AND TRAVEL BEHAVIOUR: POLICY AND INDICATORS

Lissy La Paix; Andrés Monzón, TRANSyT, Universidad Politécnica de Madrid;

Elisabetta Cherchi, DTU Transport, Technical University of Denmark

Corresponding author:

Lissy La Paix, l.c.lapaixpuello@utwente.nl

Abstract

Due to the necessity to undertake activities, every year people increase their standards of travelling (distance and time). Urban sprawl development plays an important role in these "enlargements". Thus, governments invest money in an exhaustive search for solutions to high levels of congestion and car-trips. The complex relationship between urban environment and travel behaviour has been studied in a number of cases. Thus, the objective of this paper is to answer the important question of which land-use attributes influence which dimensions of travel behaviour, and to verify to what extent specific urban planning measures affect the individual decision process, by exhaustive statistical and systematic tests. This paper found that a crucial issue in the analysis of the relationship between the built environment and travel behaviour is the definition of indicators. As such, we recommend a feasible list of indicators to analyze this relationship.

Keywords: Land-use, forecasting, indicators, policy.

Introduction

The phenomenon called *Urban Sprawl* is produced by the movement of population from the city centre to low density urban areas, with poorer accessibility and facilities, and as a consequence, high car-dependency. City structures are changing from mono-centric to polycentric cities (Gordon, 1986; Small and Song, 1992; Clark, 1994; McDonald, 1994; Cervero, 1997). This controversial term has received a lot of attention in recent years due to its association with the environment, health, transport and public investments, and to improve our understanding of the relationship between travel behaviour and urban structure (Giuliano, 1993; Handy, 1996). This phenomenon includes low density developments which are more difficult and expensive to serve by more efficient transport modes. Urban Sprawl is also called the "development trap" that leads to further congestion and a higher proportion of our time spent in slow moving cars (Ortuzar and Willumsen, 2011).

According to the Action Plan of Urban Mobility, (European Commission 2009) urban mobility is an issue of growing concern to citizens. Nine out of ten EU citizens believe that the traffic situation in their area should be improved (European Commission (EC) 2007a). The choices that people make in the way they travel will affect not only future urban development but also the economic well-being of citizens and companies. It will also be essential for the success of the EU's overall strategy to fight against climate change, achieve the 20-20-20 objective and to promote cohesion.

Urban mobility is also a central component of long-distance transport. Most transport, both passenger and freight, starts and ends in urban areas and passes through several urban areas on its way. Urban areas should provide efficient interconnection points for the trans-European transport network and offer efficient 'last mile' transport for both freight and passengers. They are thus vital to the competitiveness and sustainability of our future European transport system.

In the report "Green Paper of Urban Transport" the European Commission considers urban sprawl an important indicator of urban mobility in Europe. Urban sprawl and other factors, such as demography, congestion, the environment, employment, etc., form the diagnostic of urban and non-urban areas at an EU level. As stated in the report, "Urban sprawl is commonly used to describe physically expanding urban areas". The European Environmental Agency (EEA) has described sprawl as the physical pattern of low-density expansion of large urban areas, under market conditions, mainly into the surrounding agricultural areas. A sprawling city involves drawbacks related to urban growth and planning control of land subdivision. Development is separated, land-use is anything but mixed, and there is a tendency for discontinuity in urban structure. In other words, "Sprawling cities are the opposite of compact cities – full of empty spaces that indicate the inefficiencies in development and highlight the consequences of uncontrolled growth" (European Environment Agency EEA 2006).

There is a clear sign that the urban sprawl phenomenon is increasing in European cities. Since the mid-1950s historical trends show that European cities have expanded on average by 78% while population has grown by only 33% (European Commission (EC) 2007b). And this phenomenon is mostly accompanied by negative connotations:

- Negative environmental, social and economic impacts which seriously undermine efforts to meet the global challenge of climate change.

- Major adverse impacts in terms of increased use of land, increased energy consumption and increased soil erosion threaten the natural and rural environment, increasing GHG emissions and elevating air and noise pollution to levels that often exceed human safety limits.
- A direct effect on the quality of life for city dwellers.

The extended geographical scope of urban sprawl makes this a timely research area. The Green Paper report examined urban sprawl characteristics in cities at a European level, finding that sprawl is equally evident in the vast majority of the cities examined. It seems that the key issue is to develop sprawled cities in harmony with compact forms of urban extension. In order to achieve this objective, researchers and planners need to understand the magnitude and direction of the relationship between the built environment (BE) and travel behaviour (TB).

There are at least three elements characterizing the complex relationship between the BE and travel behaviour, as discussed below:

1. Multidimensional in nature
2. Selectivity
3. Methods

Multidimensional in nature

Both BE and TB are multidimensional in nature. They are influenced by many factors, many of which depend on the considered dimension of travel demand and the specific definition of land use. That is, there are many aspects to BE, including accessibility to transit stops, presence and connectivity of walk and bike paths, land-use mix, street network density (such as average length of links and number of intersections per unit area), block sizes, and proportion of street frontage with buildings. Similarly, there are many dimensions of travel, including car ownership, number of trips, time-of-day, route choice, travel mode choice, purpose of trips, and chaining of trips.

Many different factors influence the relationship between travel demand and the BE. There is no clear consensus on which feasible measures of the BE really play a role in explaining individual mobility (Brownstone, 2008). There is also little background information to compare the influence of land use and socio-economic characteristics on different travel demand dimensions. Recent research focus on: vehicles miles driven or VMD (Handy *et al.*, 2005), tour-frequency (Limanond & Niemeier, 2004), shopping tour (Agyemang-Duah *et al.*, 1995), type of activity (Naess, 2006); modal choice or modal changes (Bento *et al.*, 2005).

Other studies (La Paix *et al.*, 2010; La Paix, 2010; La Paix, 2012) have contributed to answering the above two questions.

Selectivity

Many authors show that higher-density neighbourhoods reduce motorized trips. However, whether land-use configuration itself affects travel pattern or whether people with different travel behaviour preferences select different types of neighbourhoods in which to live is an issue open to discussion. This effect is called self-selectivity, which some authors describe as: "the tendency of people to choose locations based on their travel abilities, needs and preferences", see Litman (2005). The importance of analyzing residential self-selection is because it may confound the association between BE-TB relationship and, as a consequence, it could produce invalid results. Most studies have employed multivariate analysis and accounted for the sorting effect of socio-economic characteristics (Abreu e Silva *et al.*, 1977; Kitamura *et al.*, 2001; Van Acker, 2007); while others focus on the issue of attitude induced self-selection (Cao, 2008).

Methods and techniques

Studies from the last 15 years have used many different estimation techniques, units of analysis, empirical contexts, travel behaviour dimensions, and BE characteristics and scales, as stated in Bhat and Guo (2007). Similarly, one of the major problems is the lack of consistency of results due to multicollinearity. Correlated indicators may confound the results and lead to spurious conclusions. And, multicollinearity also constrains the number of explanatory variables predicting travel demand, which make comparison difficult.

Due to the complexity, it is crucial to carefully analyze which dimension has influence over which dimension of TB. Thus, the objective of this paper is to select a set of best indicators for modelling trip frequency. Thus, an exhaustive research has been carried out, based on statistical and systematic tests. This descriptive analysis produces a set of statistical measures for modelling trip frequency; while the model is estimated and analyzed in a later work.

The rest of this paper is organized as follows: section 2 presents the data collection process and case study, section 3 describes 3 kinds of indicators: mobility (MOB), the socioeconomic (SE) and built environment (BE); section 4 presents a discussion about the best indicators and policy implementation. And finally, section 5 concludes the paper.

Survey process and case study

This paper uses a database from a survey conducted in 2006-2007 in Madrid, a suitable case study for analyzing urban sprawl due to new urban development and substantial changes in mobility patterns in the last years. The sample included 345 households, for a total of 943 individuals, distributed as follows: 288 from the central business district (CBD), 372 from urban areas and 283 from suburban areas.

As can be seen in Figure 1, the metropolitan area of Madrid is divided into four regions: the CBD, Madrid City, Metropolitan Ring and Regional. These four regions are partitioned into eight areas around the radial highways that go from the city centre to the periphery. The population of Madrid is 3.3 million inhabitants (INE-National Institute of Statistics), while the population of Metropolitan Ring is calculated to be 2.3 million. The demographic density varies considerably. Its inner core (i.e. Madrid City) has 51 inhabitants per hectare whereas in its metropolitan ring the density is only 10.3. However, the Metropolitan Ring is growing and gaining population from Madrid municipality.

Madrid is divided into 179 municipalities and each municipality is divided into several districts, the number of which varies among municipalities from a minimum of one and a maximum of 21.

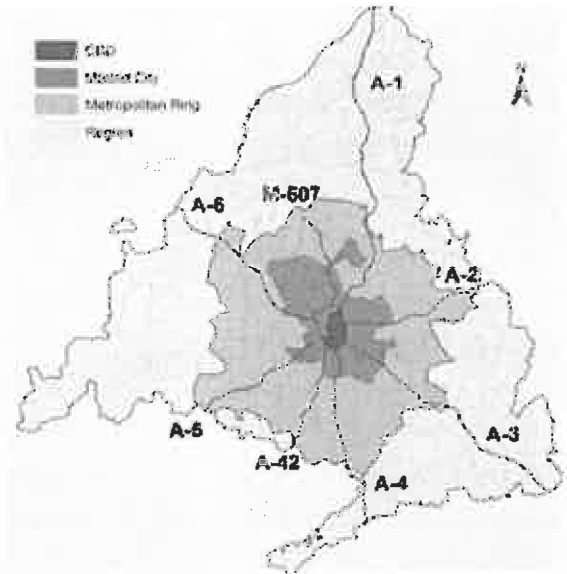

Figure 5 Location Map of Madrid

A total of 943 individuals were interviewed from 3 selected neighbourhoods: one in CBD; and 2 municipalities in the Metropolitan Ring (called urban and suburban).

Survey and data

Data come from a survey conducted with the aim to analyse the influence of the type of questionnaire on mobility patterns (Monzón de Cáceres & Madrigal Díez, 2007). The two diaries used were arranged in two parts. The first part, common to both diaries, consisted of a socio-economic questionnaire aimed at gathering data related to both the household and all its members. One member of the participating household was asked to provide information about the household and each of its members. The information collected was socio-economic and related to trips.

We combined the survey data with a GIS database and administrative data to construct three spatial levels. An exhaustive research of important indicators for measuring the relationship between land-use and travel behaviour was carried out.

Case study

As introduced in this section, the case study is composed of 2 municipalities and 1 neighbourhood. The objective of choosing 3 different residence areas is to capture the *neighbourhood type effect*. In this context, this effect occurs when a specific mobility pattern is exhibited by citizens that live in the same neighbourhood.

The CBD is located in the neighbourhood of Chamberí, which corresponds to one of the 22 neighbourhoods of the Central Business District of Madrid. It is a traditional neighbourhood where several historical buildings are located and where people live mainly in apartments. The area is characterised by good transit (bus and metro) and rail services and by a gross income level that ranks 4th out of the 22 neighbourhoods of Madrid City. In 2004 the income of Chamberí was also 40% higher than the mean of the Region of Madrid.

"Urban" is part of the municipality of Pozuelo de Alarcón, located 15 km west of the Madrid CBD but still inside Madrid City. This is a car-oriented municipality, where public transport service is limited. Urban residents tend to live in single family houses or detached houses. Pozuelo's average income level ranks the highest among the municipalities of the Region of Madrid. It was 66% higher than the mean of the Region of Madrid in 2004.

"Suburban" is a district of the municipality of Algete, that is located 30 km north-east to the Madrid CBD, in the Metropolitan Ring. This municipality has lower available gross income and fewer transit services than the other two selected areas. Algete's average income level ranks 15th among the 179 municipalities of the Region of Madrid. It was 17% higher than the mean of the Region of Madrid in 2004.

Results

Mobility indicators (MOB)

Number of Trips

The number of trips were analysed in two ways: as the total number of trips made during the survey day by each individual, and as the number of trips by mode.

Table 1 shows the descriptive statistics for trip rates grouped by residence area. Unexpectedly, the highest trip rate corresponds to the suburban area, while the lowest corresponds to the CBD. A possible explanation could be the age of respondent, because, as reported below in the descriptive analysis of socio-economic characteristics, Chamberí has the largest elderly population among the 3 neighbourhoods. Additionally, trips shorter than 5 minutes, which are frequent in the CBD, were not registered in the questionnaire. Finally, it is important to mention that the statistics below are computed based on the whole sample (943 respondents), i.e. including also the non-travellers, i.e. people who declared no trips during the study day.

We can note in Table 1 variations between 0 (minimum) and 10 (maximum) in total trips which may indicate at least one individual with 10 trips. The range is a descriptive statistic that indicates the scattering of the sample. In this case, both CBD and Suburban residents have the maximum range. Kurtosis is larger than 2 for both CBD and Suburban neighbourhoods, which means that those observations do not follow a normal distribution. As can be seen in the table, there are 1959 trips, 567 (28.94%) from the CBD, 768 (39.20%) from urban and 624 for suburban (31.85%).

The box and whisker plot for total trips is presented in Figure , the stars in the plot indicates the outliers. As can be seen, the mean is equal to 2 trips, and the 25 and 75 percentile are also equal to 2, therefore, the box is barely visible. The number beside the stars is the number of the observation. On average the three zones present similar patterns, but a higher level of dispersion is observed in the CBD and suburban neighbourhood as the mean of higher trip frequency values.

Table 1: Descriptive Statistics for Total Trips

Residence Area	CBD	Urban	Suburban	Total
Mean	1.97	2.06	2.2	2.08
Median	2	2	2	2
Sum	567	768	624	1959
Minimum	0	0	0	0
Maximum	10	8	10	10
Range	10	8	10	10
Standard Deviation	1.51	1.46	1.59	1.52
Variance	2.28	2.13	2.53	2.3
Kurtosis	2.64	0.91	2.53	2.03
Skewness	0.93	0.52	1.02	0.82
% of total	28.94	39.2	31.85	100

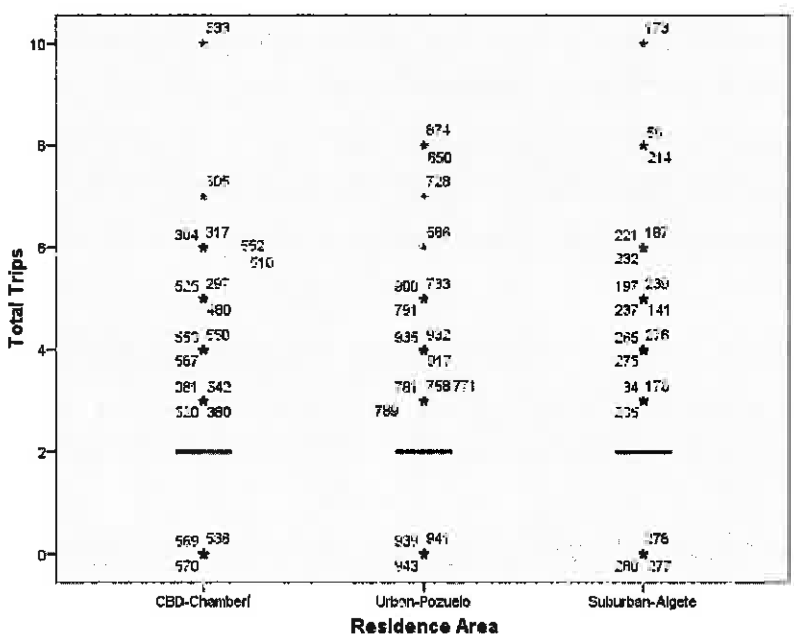

Figure 2: Box and Whisker Plot for Total Trips

Public transport trips

Table 1 shows the descriptive statistics for public transport trips rates grouped by residence area. As expected, the highest trip rate corresponds to the CBD. This is consistent with the transport service measured and displayed afterwards in the table.

The global range was between 0 and 5, which means that there was at least one individual with 5 trips. In this case, CBD takes the maximum range. Similarly, Table 1 shows 526 trips, 242 (46.01%) from CBD, 180 (34.22%) from urban, and 104 for suburban (19.77%). The box and whisker plot for public transport trips is presented in **Fehler! Verweisquelle konnte nicht gefunden werden.**. As can be seen the mean is close to zero in the three neighbourhoods. However, in the CBD 50% of the individuals carried out between zero or two trips by public transport. Similarly, the highest number of public transport trips is observed in CBD (5 trips), while Urban and Suburban areas also present zero trips on average.

Table 2: Descriptive Statistics for Public Transport trips.

Residence Area	**CBD**	**Urban**	**Suburban**	**Total**
Mean	0.84	0.48	0.37	0.56
Median	0.00	0.00	0.00	0.00
Sum	242	18	104	526
Minimum	0.00	0.00	0.00	0.00
Maximum	5.00	4.00	4.00	5.00
Range	5.00	4.00	4.00	5.00
Standard Deviation	1.10	0.93	0.88	0.99
Variance	1.21	0.86	0.77	0.98
Kurtosis	0.10	1.94	4.75	1.54
Skewness	0.94	1.71	2.34	1.55
% of total	46.01	34.22	19.77	100

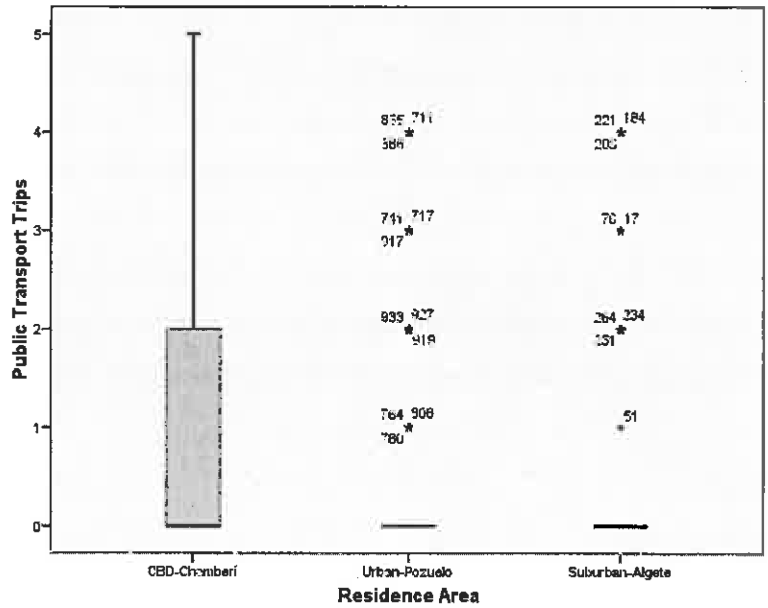

Figure 3 Box and Whisker Plot or Public Transport trips

Car trips

Table 2 shows the descriptive statistics for car-trips grouped by residence area. The table shows that the highest car-trip rate corresponds to the suburban area, which is exactly the opposite situation we found in the public transport analysis by residence area.

Similar to total trips, the global range is between 0 and 10, which means that there is at least one individual that carried out 10 trips, with Algete exhibiting the maximum range.

As can be seen in Table 2 there are 1009 trips, 136 (13.48%) from CBD, 469 (46.48%) from urban and 404 (40.04%) from suburban areas. The box and whisker plot for total trips is presented in Figure 3. The stars in the plot indicate the outliers, and there are more outliers in the CBD than in the other 2 neighbourhoods. As can be seen the mean for car-trips for the CBD is close to zero, and the 25 and 75 percentile are also close to zero, therefore, the box for the CBD area is barely visible. The number next to the stars is the number of the observation. In the case of urban and suburban, the box indicates that 50% of individuals are between 0 and 2 car-trips.

Table 3: Descriptive Statistics for Car-Trips

Residence Area	CBD	Urban	Suburban	Total
Sample Size	288	372	283	943
Mean	0.47	1.26	1.43	1.07
Median	0	1	2	0
Sum	136	469	404	1009
Minimum	0	0	0	0
Maximum	5	8	10	10
Range	5	8	10	10
Standard Deviation	0.96	1.47	1.6	1.44
Variance	0.93	2.17	2.55	2.06
Kurtosis	3.57	1.83	3.11	3.1
Skewness	2	1.17	1.33	1.48
% of total	13.48	46.48	40.04	100

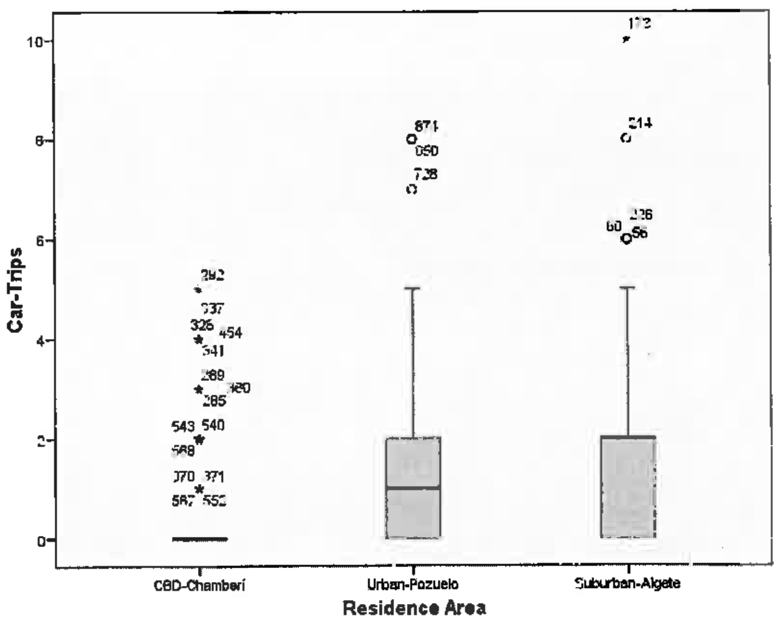

Figure 4: Box and Whisker lot for Car-Trips

Tour complexity

In our context tours are defined as a sequence of trip segments in the full day activity pattern. According to this definition, stops at home during the day are considered as intermediate stops inside the tour, instead of being considered as the end of the tour. A stop is considered as an intermediate (secondary) activity undertaken between the primary activity and home, or vice versa, between home and the primary activity.

In this paper we define a tour as the sequence of trips made during the whole day and identify a classification of the tours (called tour complexity) based on the primary activity in the tour and the number of stops.

A tour track was defined for each individual, and the number of stops during the tour accounted for. A hierarchy of activities was established in order to construct the tour track. The hierarchy of activities was created and used to identify primary activity during the day, in the case of several trips and/or stops. According to this hierarchy, the primary activity is used to classify the tour into five categories that compose the alternatives:

1. Home
2. Work or study
3. Work or study with intermediate stops
4. Non-work or non-study
5. Non-work or non-study with intermediate stops

Table 4 illustrates statistics for the frequency of each type of tour, classified according to the hierarchy and list of 5 tours explained before.

Table 4: Descriptive Statistics for Type of Tour (values in percentages)

Residence Area	**CBD**	**Urban**	**Suburban**	**Total**
HOME	24.31	22.04	21.85	19.08
Work or study	44.79	45.43	46.34	49.12
Work or study with stops	14.24	15.86	15.48	16.25
Non-work or non-study	11.46	8.06	9.01	7.77
Non-work or non-study with stops	5.21	8.60	7.32	7.77
Total	**100**	**100**	**100**	**100**

Table 4 reports the descriptive statistics for number of stops grouped by residence area. The number of stops is the sum of all the intermediate stops made in tours. As can be seen (line "Sum"), there are in total 127 stops, of which 31 (24.41%) are from the CBD, 52 (40.94%) are from urban, and 44 (34.65%) are from the suburban area. Additionally, the highest mean corresponds to the suburban area. This means that people living in the outskirts are likely to be conducting multistage tours. A possible reason for this is that in the same trip people carry out many activities before returning back home. Thus, multistage tours act as a way tocompensate local deficiencies.

The sample size is the number of individuals interviewed in each neighbourhood. The mean represents the average number of intermediate stops done by individuals residing in a neighbourhood. The table shows that residents from Algete carried out more stops than residents from the CBD. This is unexpected because the CBD is endowed with more commercial retail outlets and facilities; a possible explanation for this is that the survey only considered trips longer than 5 minutes. The skewness is positive in all of the 3 areas, which indicates that in all 3 neighbourhoods tours are mainly characterised by few or zero stops, or that there are many individuals who did not travel during the survey day.

Table 5: Descriptive Statistics for Number of Stops

Residence Area	CBD	Urban	Suburban	Total
Sample Size	288	372	283	943
Mean	0.11	0.14	0.16	0.13
Median	0	0	0	0
Sum	31	52	44	127
Minimum	0	0	0	0
Maximum	3	3	4	4
Range	3	3	4	4
Standard Deviation	0.44	0.44	0.56	0.48
Variance	0.19	0.19	0.31	0.23
Kurtosis	23.62	14.71	21.89	21.49
Skewness	4.71	3.62	4.41	4.33
% of total	24.41	40.94	34.65	100

Table 6 shows the percentages of trips grouped into four categories: 3 municipalities of case studies and otherwise. The municipality called the CBD includes 21 districts of Madrid. Urban and suburban refers to the study cases, and otherwise means all other municipalities.

Internal or *urban trips* are those trips undertaken within the municipality of residence. *Interurban trips* are those undertaken between two different municipalities.

As we can observe in the table, 85% of trips from the CBD are carried out within the Madrid CBD; while suburban dwellers undertake 37% of their trips to the CBD and 38% of their trips are undertaken within the Suburban area (municipality of residence) and only 24% to other municipalities as destinations. By contrast, urban dwellers frequently come to city centre with 53% of trips, and similar to suburban dwellers, around 35% of their trips are carried out inside the municipality of residence. This may be due to public transport service in the urban area, which is better than the Suburban one, i.e. endowed by Rail service (Cercanias). The percentage of interurban trips (both to the CBD and to other destinations) is really high. Thus, it must be carefully analyzed, (i.e. by trip purpose and mode) as a way to compensate for local deficiencies.

Table 6: Urban and Interurban Trips (values in percentages)

Residence Area	**CBD**	**Urban**	**Suburba n**	**Others**	**Total**
CBD	**85**			15	100
Urban	**53**	36%		12	100
Suburban	38		**38**	24	100

Socioeconomic Indicators (SE): the effect of the BE and life-style

The average age does not vary among neighbourhoods. However, a more disaggregated analysis reveals that the age distribution is instead quite different. Table 7 shows that individuals between 22-29 years old and between 50-64 years old are mainly located in the Urban area and in the CBD rather than in the Suburban area, while individuals aged 30-49 and 14-21 mainly live in the Suburban area. However, empirical analysis on the joint decision between number of trips and residential location have shown that age does not have an effect on the residential location choice.

The results in Table 7 might be related to the fact that families with children prefer to live in the Suburban and Urban areas. In fact, there are some differences in the household size among the three zones. Table 7 shows that households with 4 members are much more frequent in urban and suburban areas than in the CBD. According to the Census data, the municipality of Algete has an average of 3.29 members per household and Pozuelo de Alarcón 3.38; both are higher than the Madrid Community average, of 2.88 and higher that the average for Metropolitan-North (3.20). Thus, despite the outliers observed in the CBD, on average, larger household sizes are observed for the urban and suburban areas.

Household size seems to be related to the neighbourhood selection. And of course the structure of the family and the status of the individuals are also related to the type of neighbourhood they live. Usually families with children prefer a bigger house which results in a lower density area. In fact, the Suburban area shows the highest percentage of married people (Table 7) and similarly the highest percentage of households with children.

Table 7: SE indicators (values in percentages)

Residence Area	CBD	Urban	Suburban
Gender			
Male	48	49	54
Female	52	51	46
Total	**100**	**100**	**100**
Age			
4-13 years	5	5	8
14-21 years	12	11	18
22-29 years	11	15	8
30-49 years	25	23	37
50-64 years	30	37	19
Greater than 65 years	17	9	10
Total	**100**	**100**	**100**
Household size			
1	8	1	2
2	24	15	18
3	27	26	25
4	26	42	45
5	9	13	10
6	2	3	
7	2		
Total	**100**	**100**	**100**
Marital Status			
Single	43	38	31
Married	51	57	64
Widow	4	3	1
Divorced	2	1	3

Total	100	100	100
Presence of child			
No Child	80	73	63
One or more	20	27	37
Total	**100**	**100**	**100**
Employment Status			
Worker	51	51	55
Work/study	2	2	1
Student	20	21	19
Retired/ Unemployed	20	16	18
Other Occupation	7	10	7
Total	**100**	**100**	**100**

Built Environment Indicators (BE)

The set of built environment (BE) variables includes all variables that are able to describe the characteristics of the neighbourhoods. One of the variables most used in the earlier literature is a simple dummy variable associated with each type of neighbourhood considered (in this case CBD, Urban and Suburban). However, one problem with this variable is that it represents too many characteristics, whose effect cannot be disentangled.

Several variables are measured and/or computed in this paper to try to specify and differentiate the BE characteristics. These include the typical measures such as residential and employment density, but also measures less frequently used such as transport accessibility, jobs, other opportunity activity, and also characteristics of the streets. Depending on their availability, these variables were measured at the residential zone, which usually corresponds to the origin of the first trip, and/or at origin and/or destination of each individual trip. Computing BE variables at both origin and destination zones made it possible to build composite variables (such as ratios between the same variable measured at origin and destination) to capture the relative effect of each characteristic between origin and destination. Similarly, the dimension (in squared kilometres) of each zone was computed in order to normalize those variables whose values were strictly correlated with the dimension of the zone. The normalized measures enable a correct comparison among the different spatial dimensions considered in this paper.

BE variables were measured at three different zone levels: by municipalities, by district and in a radius of 600 meters around the household location (called "*residential level*").

The residential level, instead, was defined as the area in the 600 meters radio around the residence of each person interviewed.

Variables at municipal and district levels were computed using the National Institute of Statistics – INE (Spanish acronym) database. Table 8 shows the BE indicators. We discuss indicators by group in the following sections.

Table 8: BE Indicators

Description	CBD	Urban	Suburban
Land-Use Indicators			
Area of Commercial Land-use			
At origin (*in ha*)	205.59	109.77	24.53
At destination (*in ha*)	187.56	143.13	84.23
Percentage of Commercial Land-use			
At origin	0.05	0.04	0.01
At destination	0.03	0.03	0.01
Ratio of Commercial Land -use			
% Origin / % Destination	2.55	1.89	1.02
Area of Residential Land			
At origin (in ha)	9.390.04	1.626.96	422.39
At destination (in ha)	8.321.72	4.680.51	3.130.76
Percentage of Residential Land			
At origin	0.44	0.68	0.66
At destination	0.44	0.57	0.55
Ratio of Percentage Residential Land			
% Origin / % Destination	1.02	1.26	1.28
Area of Area of Industrial Land			
At origin (in ha)	1.468.89	6.18	96.92
At destination (in ha)	1.310.29	610.71	517.94
Percentage of Industrial Land			
At origin	0.07	0	0.15
At destination	0.08	0.04	0.13
Ratio of Industrial Land-use Percentage			
% Origin / % Destination	1.43	1.73	0.53
Employment Density Indicators			
Quantity of workers			
At origin	1,278,968	31,343	7,609
At destination	1,134,765	540,802	395,831
Percentage of workers			
At origin	0.41	0.39	0.4
At Destination	0.41	0.4	0.4

Ratio of workers			
% Origin / % Destination	0.99	0.97	0.99
Gross Domestic Product (GDP) (in Euros)			
At origin	38,603	51,895	34,103
At destination	37,678	43,847	36,339
Ratio			
Origin / Destination	1.06	1.25	0.98
Difference GDP and Madrid's GDP			
At origin (in %)	121.86	163.34	107.82
At destination (in %)	119.32	138.86	115.08
Ratio of Percentages			
% Origin / % Destination	1.6	1.25	0.98
Commercial retails Indicators			
Number of places within 1.2km of the dwelling. (Average)			
Eat out places	9.54	1.03	0
Medical	2.6	0.46	0
Parking	1.39	0	0
Schools and universities	17.74	10.58	6.95
Service oriented places	18.19	2.84	0.24
Dwelling type			
Single family	2%	32%	29%
Terraced House	0%	48%	33%
Detached	0%	4%	7%
Apartment	93%	14%	23%
Condominium	5%	2%	4%
Street density. Average number of intersections within 1.2km of the dwelling			
3-way	47.46	127.46	76.12
4-way	65.67	34.18	17.74
5-way	2.08	5.31	0.87
Public transport supply (Average number within 1.2 km of the dwelling, average)			
Metro stations	18.51	0	0
Bus stops	33.83	1.35	20.14
Rail stations	0	0.58	0

Land-use

The land-use (LU) variables that were possible to measure only at the municipal level at both the origin and the destination of each trip reported in the survey are:

- Urban land-use
  - Area in hectares of urban land-use
  - Percentage of urban land-use

- Ratio of Urban Land-use
- Commercial land-use
- Area in hectares of Commercial land-use
- Percentage of Commercial Land.
- Ratio of Commercial Land-use between origin and destination
- Residential land-use
- Area in hectares of residential land-use
- Percentage of Residential Land
- Ratio of residential land-use between origin and destination
- Industrial land-use
- Area in hectares of industrial land-use
- Percentage of Industrial Land
- Ratio of Industrial land-use between origin and destination

The main problem with measuring land-use at the municipal level is the lack of variability among observations. Moreover, in the case of large municipalities, such as Madrid, most of the trips start and end in the same municipality. Hence, it is impossible to distinguish the effect in the transport mobility due to differences in the land-use characteristics at origin and destination. Of course, large municipalities are not perfectly homogenous, i.e, some areas have higher concentration of commercial activities than others. However, to some extent, the ratio captures better the variability at the municipal level.

Public transport

A set of six variables was analyzed, with the aim of describing the accessibility level of destination zones regarding three different public transport modes: bus, Metro and rail (Cercanías). The number of bus stops, Metro and rail stations operating in 2008 by district and municipality are included here. The variables were calculated for both the number of units and ratio per squared kilometre. The main conclusion that emerges from this is the huge gap among destination zones; see for example in the number of bus stops by municipality.

Table 8 also shows the statistics for public transport supply by neighbourhood type. These measures are calculated at the Residence Area level, i.e. a 600m buffer around the residence. The average values show that dwellings in Pozuelo are situated close to an urban rail station; while most of the dwellers in the CBD are located close to Metro stations; there are 18 Metro stations on average around each CBD dwelling. Similarly, we can observe that availability of bus stops is really low in Pozuelo.

Commercial retails at Residence area

The number of places to eat out can be associated with the location of Residence Area and the proximity to downtown. The number of monuments and recreational places can, to a higher extent, be explained by the location of the residence relative to downtown. Residents of the outer of the two zones (Algete and Pozuelo) live further away from medical facilities than from the CBD (Chamberí). The average number of medical facilities within 1.2km is 2.6 in CBD are (Chamberí), 0.4 in the Urban area (Pozuelo) and zero in the Suburban area (Algete), respectively. The average number of service-oriented places decreases with the distance from the residence to downtown. The high standard deviation indicates that almost all dwellings in the area have a service-oriented place, but only residents of some parts of the neighbourhood have the opportunity to choose among several service-oriented places. The number of primary schools or universities is somewhat lower in the Suburban area (Algete) than in the urban area (Pozuelo), 6 and 10 respectively, while in the CBD (Chamberí) it is equal to 17.

Street density

Figure indicates the number of trips by car related to the number of cul-de-sacs by residential area. It seems that the number of car-trips increases with a greater number of cul-de-sacs. Categories of 1 or 2 car-trips tend to be higher while categories of no trips tend to decrease.

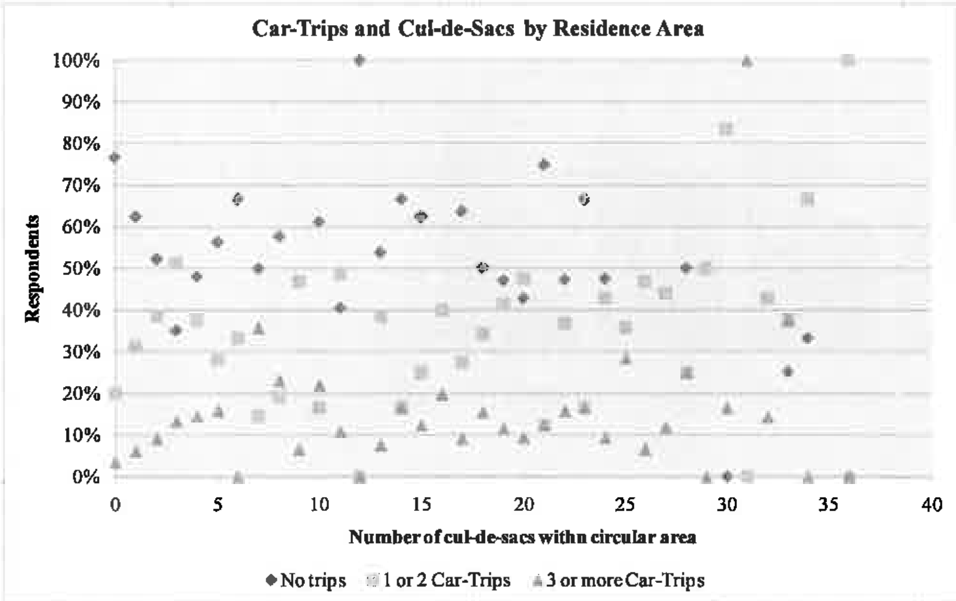

Figure 5 Car-Trips and Cul-de-Sacs by Residential Area

Distance to CBD

The distance to the CBD was calculated as the distance in kilometres between the residence of each household and the city centre. It was calculated from the household location to Madrid City centre (Km zero at Sol) through a Google Earth Application Plus (5.1 version).

Figure shows the average distance from the CBD calculated for each household, and grouped by category of car trips and public transport trips by individuals, respectively. Car and public transport categories of trips are grouped in four categories as follows:

1. Zero trips
2. 1 or 2 trips
3. 3 or 4 trips
4. 5 or more.

Figure shows that the farther the household location is from the CBD, the greater the propensity to undertake more trips by car. The fourth category (5 trips or more) shows the highest average distance of household from the CBD. It shows that the relationship between trips by public transport and distance to the CBD is less clear, demonstrating the importance of analyzing different travel dimensions regarding urban environment attributes.

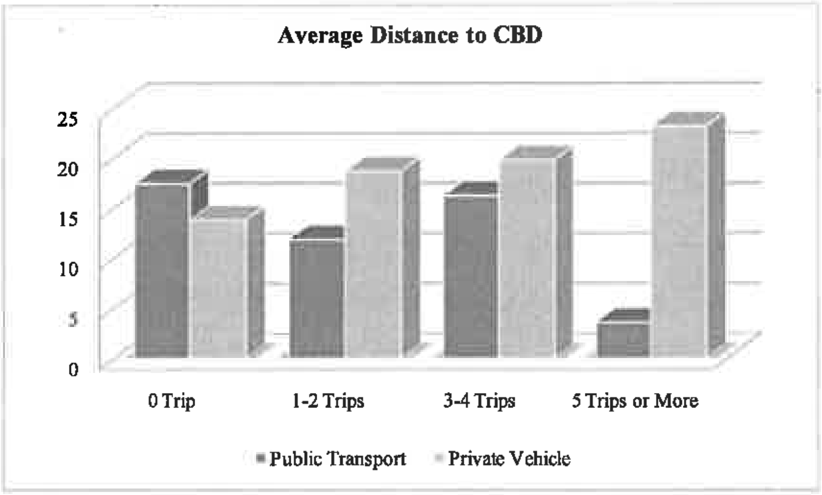

Figure 6 Car-trips and Public Transport Trips compared with distance to the CBD

Conclusions and Policy recommendations

This paper analyzed the existing literature and concluded that a crucial issue in the analysis of the relationship between the BE and TB is the definition of indicators. This multidimensional relationship needs to be carefully analyzed in order to avoid multicollinearity and biased results.

In that sense, this paper has shown a set of relevant and feasible indicators to be included in a demand model and more specifically, a demand model for estimating trip frequency from BE, SE and MOB indicators.

Through the selection of 3 neighbourhoods, the results show that neighbourhood effect is relevant for analyzing travel behaviour. Consistent with other studies in this field, one of the main findings has been that people living in outskirt areas are likely to multistage tours out of the residence area. A possible explanation for this is the desire to compensate for local deficiencies. Since must of interurban trips are carried out to Madrid CBD, commercial facilities at origin must be considered.

Particular to the case study of Madrid, it is important to point on the high percentage of interurban trips from the analyzed residence areas. In that sense, as policy makers try to harmonize sprawling cities with compact forms of urban extension, they must improve public transport between interurban origin and destinations. It is clear that trips from Urban to *CBD* are higher than Suburban to *CBD* and which is related to public transport accessibility. Thus, improvement in that sense is strongly necessary for *Suburban* areas.

The descriptive statistics of street density have shown that future urban development must consider high street density, because it decreases car-trips.

As a policy recommendation, it is important to highlight that transport demand models must incorporate more BE attributes. Similarly, transport policy measures must differentiate between the municipality and district scale for policy measures, because it is clear that we are dealing with different situations. Further research is ongoing about geographical scales for built environment attributes.

Finally, the importance of ratio measures (origin and destination of the first trip during a tour) indicates the relationship between local deficiencies and facilities at the destination. Further research is also forthcoming on this relationship by the authors of this paper.

References

Abreu e Silva, J.; Golob, T. & Goulias, KG. (1977). The effects of land use characteristics on residence and employment location and travel behaviour of urban adult workers. Transportation Research Record, 121-131.

Agyemang-Duah, K.; Anderson & Hall, WP. (1995). Trip generation for shopping travel. Transportation Research Record, (1493), 12-20.

Bento, AM; Cropper, ML; Mobarak, AM & Vinha, K. (2005). The effects of urban spatial structure on travel demand in the united states. Review of Economics and Statistics, 87(3), 466-478.

Bhat, C. & Guo, J. (2007). A comprehensive analysis of built environment characteristics on household residential choice and auto ownership levels. Transportation Research Part B: Methodological, 41(5), 506-526.

Bowman, D. & Ben-Akiva, M. (2001). Activity-based disaggregate travel demand model system with activity schedules. Transportation Research Part A: Policy and Practice, 35(1), 1-28.

Brownstone, D., (2008). Key relationships between the built environment and VMT. Transportation Research Board, , 7.

Cao, X. (2008). Exploring causal effects of neighborhood design on travel behavior using stratification on the propensity score. Paper 09-0155 on the Transportation Research Board 88th Annual Meeting CD-ROM. Washington, DC.,

Cervero, R. (1997). Polycentrism, commuting, and residential location in the san francisco bay area. Environment and Planning.C, Government Policy, 29, 865.

Clark, W. (1994). Commuting in restructuring urban regions. Urban Studies, 31(3), 465.

European Commission (EC). (2007a). Attitudes on issues related to EU transport policy. flash eurobarometer No. 206b)

European Commission (EC). (2007b). Preparation of a green paper on urban transport: Report on urban transport in europe

European Environment Agency EEA. (2006). Progress towards halting the loss of biodiversity by 2010. No. Report 5/2006). Copenhagen, the Netherlands:

Giuliano, G. (1993). Is the journey to work explained by urban structure? Urban Studies, 30(9), 1485.

Gordon, P. (1986). The distribution of population and employment in a polycentric city: The case of los angeles. Environment and Planning.C, Government Policy, 18(2), 161.

Handy, S. (1996). Methodologies for exploring the link between urban form and travel behavior. Transportation Research Part D, 1(2), 151-165.

Handy, S., Cao, X. and Mokhtarian, P. (2005). Correlation or causality between the built environment and travel behavior? Evidence from northern California. Transportation Research Part D, 10(6), 427-444

Kitamura, R.; Akiyama, T.; Yamamoto, T & Golob, T. (2001). Accessibility in a metropolis: Toward a better understanding of land use and travel. Transportation Research Record, 1780, 64-75.

La Paix, L. (2010). Relación entre la generación de viajes y la densidad urbana: Caracterización de la movilidad con modelos probit ordenados. IX Congreso Ingeniería del Transporte CIT. 5 -7 July, 2010. Madrid, Spain

La Paix, L., Monzón, A. and Cherchi. E. (2010). Trip generation and location effects: case study of Madrid Metropolitan Area. 12th World Conference on Transport Research, 11 -15. Lisbon, Portugal, July 2010.

La Paix, L. (2012). Modelling the impact of built environment, geographical scales and latent constructs on individual travel behaviour. Doctoral Thesis, Universidad Politécnica de Madrid.

Limanond, T. and Niemeier, D.A. (2003). Accessibility and mode-destination choice decisions: Exploring travel in three neighborhoods in puget sound, WA. Environment and Planning B, 30(2), 219-238.

Litman, T. (2005). Land use impacts on transport: How land use factors affect travel behavior.Victoria Transport Institute.

McDonald, JF. (1994). Suburban employment centres: The case of Chicago. Urban Studies, 31(2), 201.

Monzón & Madrigal (2007). Mejora metodológica de encuestas de movilidad de viajeros para el análisis de la demanda de transportes en españa. Estudios De Construcción y Transportes, (106), 93.

Naess, P. (2006). Accessibility, activity participation and location of activities: Exploring the links between residential location and travel behaviour. Urban Studies, 43(3), 627.

Ortuzar, J. D., & Willumsen, L. G.,(2011). In Modeling transport. John Wiley & Sons (Ed.), Chichester, UK.

Small, K. and Song, S. (1992). "Wasteful" commuting: A resolution. Journal of Political Economy, 100(4), 888.

Van Acker, V. (2007). The effects of the land use system on travel behavior: A structural equation modeling approach. Transportation Planning and Technology, 30(4), 331.